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Aviation common ground support equipment replacement policy investigation

Patterson, Ronald Gilbert; Bradley, Fred

Monterey, California. Naval Postgraduate School

NAVAL POSTGRADUATE SCHOOL

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THESIS

AVIATION COMMON GROUND
SUPPORT EQUIPMENT REPLACEMENT
POLICY INVESTIGATION

by

Ronald Gilbert Patterson

and

Fred "H" Bradley, Jr.

March 1977

Thesis Advisor: J. C. Larson

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(20. ABSTRACT Continued)

utility. Several areas for future research are also suggested to improve the program viability.

Aviation Common Ground Support Equipment Replacement Policy Investigation

by

Ronald Gilbert Patterson
Commander, United States Navy
B.S., University of Washington, 1961

and

Fred "H" Bradley, Jr.
Lieutenant, United States Navy
B.S., Purdue University, 1968

Submitted in partial fulfillment of the requirements for the degree of

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March 1977

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I. INTRODUCTION

A. BACKGROUND

The Department of Defense (DOD) has long enjoyed the reputation of being an innovator in new management techniques. Operations Research, Linear Programming, Computerized Production Scheduling, Organizational Development and a host of other current industrial programs have had their genesis in the Department of Defense.

One such technique although not originated within DOD, has been used and promoted in DOD in recent years and promises to enjoy a re-birth in the private sector. Equipment Replacement theory was baptized shortly after World War II and has been embraced only recently by the three services.

Equipment Replacement theory involves one type of a capital investment decision process, deciding whether an asset should be retained for a longer period of time or replaced. The basic question to be resolved is when should an existing equipment be replaced from an economic point of view. A good replacement policy requires not only a good methodology, but also it needs a good organization to administer the policy with the support of top management. The methodology involves historical data collection and use of mathematical models, both of which will be addressed in detail in this work.

Professor John I. S. Hsu of Villanova University conducted a survey of private-sector equipment replacement practices in 1974 (Hsu). In this survey, Professor Hsu reviewed forty-six of the largest manufacturing firms in the nation and determined that twenty-four (52%) of the companies did have a firm replacement policy and used a specific formula. The other twenty-two firms did not have a company policy, but used subjective judgement. Perhaps of greatest interest to the military, is the information tabulated in Tables I and II.

TABLE I

ELEMENTS USED IN THE EVALUATION OF REPLACEMENT CYCLE

	Element	Number of Firms
1.	Repair & Maintenance Costs	24
2.	Cost of Downtime	19
3.	Revenue	16
4.	Obsolescence factor	12
5.	Acquisition cost	10
6.	Salvage Value	4
7.	Taxes	1
8.	Inflation Rate	1

Note: 1. Elements not mutually exclusive.

2. Each firm used a combination of elements.

TABLE II

THE PROBLEMS OF DETERMINING ECONOMIC LIFE

The Most Difficult Problem	Number of Firms
1. Forecast of Technological Change	9
2. Accuracy of cost data	5
3. Estimate of equipment utilization	3
4. Measurement of indirect savings	2
5. Effectiveness of original design	2
6. Not answered	3
TOTAL	24

These elements considered so important in the private sector are also of great concern to the military and represent, indirectly, the purpose for this thesis.

The Navy has an equipment replacement policy for several equipment types, such as Construction Equipment, Material-handling equipment and Common Ground Support Equipment (CGSE). (Defense) It is this last category which this work will address. As a specific example of this type of equipment The TA-75, a self-propelled aircraft tow tractor will be used. The Navy uses the TA-75 and JG-75 for towing medium-weight aircraft ashore. A similar unit, the MD-3, is used aboard aircraft carriers. Large aircraft are towed on shore

by TA-18s, TA-180s and WLF-18s — all essentially identical units.

There are four models of TA-75s: The United TA-75, TA-75A, TA-75B and the Hough TA-75. The JG-75 has three models: The JG-75, JG-75-1 and JG-75-2. TA-75s and JG-75s are essentially similar, differing only in that the TA-75 is a newer, more versatile unit with a V-8 engine as opposed to the 6-cylinder JG-75.

The Navy CGSE equipment replacement policy, implemented by NAVAIRINST 4411.1 represents a first step in minimizing the cost of CGSE ownership. The importance of such a policy is readily understandable when one considers the cost of the Navy CGSE. The Navy owns well over one hundred thousand individual CGSE units, valued at over $2.5 billion. The replacement cost of these units ranges from a few dollars to well over $1 million per unit. It is therefore not only natural, but also imperative that the Navy devise a management technique to minimize cost-of-ownership. Unfortunately, the current policy does not fulfill the stated objectives.

1. Purpose

The objective of this study is to evaluate the Navy's CGSE replacement policy and recommend changes to increase its utilization and effectiveness. To accomplish this objective, a thorough investigation of accepted equipment replacement models is conducted. The need for a CGSE replacement model, the theory and construction of representative models and sensitivity analysis are investigated.

Finally, and most pertinent, the Navy's CGSE replacement model is critically examined. The Naval Air Systems Command's (NAVAIRSYSCOM) CGSE replacement policy (currently referred to as the "Retirement Program") is considered deficient in the following areas (page numbers refer to applicable pages in this thesis):

a. The NAVAIR model requires certain assumptions which may or may not be relevant, such as: (1) a certain cost of capital, (2) zero salvage value, (3) rising annual maintenance costs and (4) identical operator cost between the old machine and its prospective replacement (pages 21-23).

b. The model relies upon imperfect data as an essential input parameter. Not only is the data inaccurate, but it is also inconsistent: a crippling deficiency (page 42).

c. The current program does not sufficiently correlate the replacement decision with the procurement process (page 43).

d. Fleet maintenance policies have a significant impact upon the computed CGSE economic life. The current program fails to integrate maintenance policy with the replacement decision process (pages 44-48).

e. Procurement policies are driven by replacement policies to a certain extent. The current replacement policy fails to recognize the impact of other older or similar equipments which serve as valid

alternates to the prime item on the actual replacement action (page 48).

f. A CGSE renewal (i.e. "make-like-new") action is not accommodated by the current model. When a CGSE unit is not in danger of becoming functionally obsolete, the renewal action may enjoy a cost advantage over replacement (pages 49-52).

g. The effects of reliability and maintainability improvements inherent in the prospective replacement are not considered adequately (page 49).

h. The critical aspects of timing and procurement lead time are not sufficiently addressed (pages 53-55).

These deficiencies are reviewed in detail and recommendations to improve the model validity and viability are offered.

II. REPLACEMENT MODELS

A. NEED FOR REPLACEMENT MODELS

Replacement models fall into two broad interlocking categories depending upon the life pattern of the equipment under study. The first model category considers equipment that deteriorates over time; the second considers a unit that fails completely and instantaneously. A spectrum of possible equipment conditions may be envisioned which fall between the two extremes cited above. When replacement is being considered, evaluation must be performed to ensure the benefits associated with a new replacement unit exceed anticipated benefits of retaining the current asset. These benefits are generally measured in terms of cost savings over a specified time period. The success of a military organization is measured not in terms of increased dollar profits, but by the successful accomplishment of a mission with minimum allocation of men, money and materials. With this in mind, the successful military economic equipment replacement model should predict replacement at the point where manpower, material and money expenditures are minimized while retaining the level of mission accomplishment desired.

Replacement of an asset before the unit is completely worn out appears to be a *prima facie* contradiction to the minimum operating cost theory in the sense that the unit obviously is capable of some amount of future production above the required level of mission accomplishment. The

reluctance to replace a physically satisfactory but economically (men, money or material usage) inferior piece of equipment is due in part to the fact that the decision to replace is much more binding than the decision to continue with the present asset. Another perceived detriment in making the decision to replace an existing asset is that the current on-hand asset is yielding a production that can be renewed at any time whereas the decision to replace is a commitment for a longer period into the future. In essence, a "do-nothing" decision represents less obvious risk than a decision to replace would represent. The following represent the more common reasons precipitating replacement actions. (Fabrycky)

1. <u>Replacement Because of Inadequacy</u>

An item of CGSE may be incapable of meeting the changing demand required of it. This often is the effect upon equipments that have a fixed capacity and changing operational requirements begin to demand more capacity. To illustrate, a motor may not be able to meet an increased load or a TA-75 aircraft tow tractor may not be capable of towing new types of heavier aircraft. In each case, the piece of CGSE may be in excellent condition, but it now must be considered for replacement due to the need for greater capacity, or its failure to meet the new level of mission effectiveness standards now required.

2. <u>Replacement Because of Obsolescence</u>

New equipment is continually being developed that will perform the same function as existing CGSE items but at substantial cost savings. When this is true, *ceteris paribus*, the existing asset should be replaced because of its technological obsolescence. The existing CGSE unit may still be capable of performing the production demands placed upon it without incurring excessive maintenance cost and may still be operating at a satisfactory level of operating efficiency. If, however, an economic savings in manpower, monies or material can be gained by replacement, then the existing item of CGSE should be retired.

3. <u>Replacement Because of Excessive Maintenance</u>

Items of CGSE rarely incur uniform wear. Individual CGSE components are likely to deteriorate faster and fail before others. Under these conditions, it is often the economical solution to repair the component and extend the useful life of the asset. Diverse types and degrees of maintenance and repair, coupled with widely-ranging costs, may dictate replacement as an attractive economic alternative as opposed to repair.

At a certain point in an asset's life, the anticipated repair cost should be compared with the expected replacement cost, especially when these repairs can be viewed as extensive and/or additional and excessive repairs are foreseeable. The alternative possessing the lowest cost

should be selected. This replacement has a weakness in that although it will identify the time period for which the lowest equivalent average annual cost occurred, it does not necessarily follow that the greatest economy would have occurred at the minimum point indicated. This result would totally depend upon the cost and characteristics of the replacement item of CGSE.

4. Replacement Because of Declining Efficiency

Equipment generally operates at an initial peak efficiency, but through the passage of time and as a consequence of usage, the efficiency gradually declines. The reduction in efficiency may require increased power consumption and longer use to accomplish the same operation or mission. This generally results in increased operational cost and can be therefore analyzed in a similar manner as those items requiring replacement because of excessive maintenance.

5. Replacement Under Inflation and Increased Productivity

Inflation and increased productivity are realities that play an important part in the decision environment. Although both may have an effect upon the procurement and use of CGSE, they are usually disregarded in replacement models, because of their unpredictability. When it can be assumed that the rate of inflation and increased productivity are consistent rather than sporadic over time, their effects can and should be made part of the decision for equipment replacement. For the TA-75, future procurements will likely

involve units basically similar to the existing unit. Therefore, no significant productivity increase in envisioned. In view of the net mission requirements of the Navy remaining status quo or increasing with a boundary applied to the resources available to perform the mission required, two different meanings may be applied to increased productivity: (1) a decrease in the men, monies and materials input to obtain a constant output, or (2) an increase in output resulting from the same amount of men, monies and materials input. Evaluation of inflation and increased productivity disclose that inflation with no increase in productivity will result in equipment replacement before the service life is obtained. Inflation with increasing productivity reverses the effects of inflation and causes a replacement policy favoring the use of equipment until the end of their service life (Fabrycky).

The difficulty in applying this model to a military environment is that the model requires quantitative money figures instead of incommensurables such as mission performance.

B. STANDARD REPLACEMENT MODELS

Six comprehensive methods are used today as a means to determine the time at which capital equipment should be replaced (NAEC REPORT - Rhoades). They are:

1. Annual Cost Method
2. Present Worth Method
3. Rate of Return Method

4. The First MAPI (Machinery and Allied Products Institute) Method
5. The Second MAPI Method
6. The Third MAPI Method

All of these methods involve comparing the documented cost of the old machine with the expected cost of the replacement. Costs, however, are seldom uniform. Furthermore, some costs are present-day costs and some are anticipated future costs. To further complicate the issue, the time-value of money must be considered. A dollar today is worth one dollar. At an assumed interest rate of 10%, a dollar today is worth $1.10 a year from now. A dollar cost anticipated to be incurred one year from now represents a present cost of $0.91. Therefore, in evaluating the costs and benefits associated with each alternative, the present and future value of money must be accounted for, as well as ensuring that each equipment is evaluated on the same basis; i.e., non-uniform disbursements must be converted to uniform disbursements to standardize the comparison.

1. The MAPI Methods

The three MAPI methods were developed primarily for use in evaluating machine tools and exhibit their full potential in that context.

MAPI assumes that certain operational costs begin to rise linearly starting with the first year; the rate of rise being termed the gradient. The MAPI method is the only method which assumes non-uniform disbursements increase

linearly. For factory machine tools, this assumption is valid. For GSE, it is not. In comparing the old machine (defender) with the new machine (challenger), the savings in operating cost that would be realized should the replacement be effected is divided by the age of the defender. This quotient is considered the gradient for the challenger. Using this gradient then, the planner calculates the lowest uniform annual average cost to determine the new economic life of the challenger. The cost-linearity assumption and the use of arithmetic averages for exponential curves limit the use of the MAPI method for GSE retirement and will not be considered further. The second and third MAPI methods use discounted cash flows, assumed earnings (revenues) and figures-of-merit, further limiting their applicability to the GSE situation.

2. <u>The Annual Cost Method</u>

The Annual Cost Method, Present Worth Method and Rate of Return Method are all general methods and are based on the same assumptions. Their differences lie in the method by which the same final results are presented. Since the three methods yield the same results, only the annual cost method will be examined to determine its essential parameters.

The uniform annual cost method consists of:

1. Listing all costs affecting a comparison between the old and new machines.

2. Using the past history of the old machine to predict future costs of both machines.

3. Converting present and future costs into uniform annual costs (disbursements) for each year of the possible service life.

4. Summing the annual costs for each year of the possible service life.

5. Choosing the least-cost alternative.

Generally, the uniform annual cost method as implemented by NAVAIR assumes (1) the same operational cost for each machine (thus eliminating operational cost as a differential cost, in the accounting sense), (2) no salvage value for either machine, (3) a continuing need for the service the machine performs and (4) the maintenance costs for each year are higher than the preceding year. These assumptions are not basic to the model developed, however, and each assumption may be eliminated or modified without degrading the model validity. The term "operational cost" used above refers to the labor cost of operating the machine.

Initially, the acquisition cost of the new machine must be prorated over the engineering service life to effect a comparison between the old and new machine. If the time-value of money is ignored, the average capital cost of a $1000 machine over two years is $500. However, if money costs 10%, the average cost becomes $576 per year ($1000 x .576). Thus, considering that there is a time-value to money, the average capital cost over a specified period of time is determined by multiplying the acquisition cost by a capital recovery factor, which is the amount of an annuity

(equal payment) paid over that specified period and whose present value is one dollar. Table III illustrates the difference caused by considering the time-value of money.

TABLE III PRORATING ACQUISITION COSTS

YEARS	CAPITAL RECOVERY FACTOR		CAPITAL RECOVERY	
	0 % Interest	10%	0%	10%
0				
1	1.000	1.100	$1000	$1100
2	0.500	0.576	500	576
3	0.333	0.402	333	402

It is significant at this point to distinguish between "service life" and "economic life". Service life is determined by the manufacturer's engineers as a physical expected useful life based upon average maintenance practices. Economic life is a computed length of time, at the end of which the total average annual cost is at its minimum point. Exceeding the service life is to invite eventual degradation of physical utilization. Overhaul or extensive repair can temporarily extend the service life, however. Exceeding the economic life results in a higher total average annual cost. No mechanism is available to extend the economic life: further operation of the equipment can only result in higher costs, given the general model characteristics cited herein.

The generally accepted relevant costs for the annual cost method are maintenance costs and capital recovery costs. The model may be expanded, however, by assuming (correctly) that gas and oil consumption increases with age, operator wages increase yearly and parts cost increase with the passage of time. Furthermore, the rates of increase will differ between the old and new machines. Inflation rates may be assumed if the planner has reason to suspect the rates in future years will be significant.

Possibly the best way to illustrate the method is to present an example. Assume the existing equipment is five years old and the rising cost of operating and maintaining the machine have become substantial. Further cost can be avoided if the old machine is replaced by a similar new machine. A capital expense will be incurred upon delivery of the new machine. Both operational and maintenance costs will be incurred in the following years. The anticipated yearly costs will be non-uniform and not entirely predictable, but are based upon previous documented experience with the old machine.

The following assumptions apply to the new machine where the cost of capital is <u>not</u> considered.

a. Operations Cost: assumed to be \$4000 for the first year for gas, oil and operator salary. This figure is inflated at 4% per year and $\frac{1}{2}$% per year added to reflect decreased fuel economy and increased oil consumption.

b. Maintenance Cost: Assumed to be \$1200 for the first year. Figure inflated 4% and 4% added per year to reflect increasing maintenance cost due to wear, tear and age.

c. Book Value: Initial acquisition cost assumed to be \$9000. Economic life established by NAVAIR set at 10 years.

d. Salvage Value: "Blue Book" concept is used in that the resale value is assumed to decrease exponentially with time. Salvage (resale) value assumed to be $S_n = 5000\ e^{-0.23t}$ which assumes the \$9,000 unit could be sold immediately after purchase for \$5,000 and for \$500 at the end of 10 years.

Table IV tabulates values to construct Figure 1. The tabulated values satisfy the equation

$$ATC_n = \frac{P_o - S_n}{n} + \frac{\sum_{j=1}^{n} (O_j + M_j)}{n}$$

where:

P_o = purchase price

S_n = Salvage value in year "n"

O = Operations cost

M = Maintenance cost

n = end of year "n"

ATC_n = Average total annual cost over n years.

The point at which the lowest uniform average cost occurs for the new machine is seen to be 6 years, and the average annual cost over its economic life is approximately \$7,235 per year. The economic life for the new machine is therefore computed to be 6 years.

If the time value of money (capital) is considered for the same machine, a different economic life is obtained. Using the same assumptions, but additionally assuming a 10% cost of capital, the values seen in Table V and Figure 2 are obtained. The economic life is now observed to be 7 years and the total Equivalent Annual Cost is approximately \$7735.

The tabulated values in Table V satisfy the equation

$$EAC_n = P_o - \frac{S_n}{(1+i)^n} + \sum_{j=1}^{n} \frac{(O_j+M_j)}{(1+i)^j} \quad \frac{i(1+i)^n}{(1+i)^n-1}$$

where EAC_n = Equivalent Annual Cost over n years.

i = Discount Rate (DOD cost of capital, 10%)

The other symbols are identical to those in Figure 1 (equations taken from Shamblin and Stevens).

End of Year	Trade-in	Invest- ment Cost	Operation Cost	Maint- enance Cost	O & M Cost	Σ O & M Cost	Average O & M Cost per Year	Average Invest- ment Cost per Year	Total Average Annual Cost
1	2	3 = Po- 2	4	5	6 = 4 + 5	7 = Σ 6	8 = 7 / 1	9 = 3 / 1	10 = 8 + 9
1	3973	5027	4000	1200	5200	5200	5200	5027	10227
2	3156	5844	4180	1296	5476	10676	5338	2922	8265
3	2508	6492	4368	1400	5768	16444	5481	2164	7645
4	1993	7007	4565	1512	6077	22521	5630	1752	7382
5	1583	7417	4770	1633	6403	28924	5785	1483	7268
6	1258	7742	4985	1763	6748	35672	5945	1290	**7235**
7	999	8001	5209	1904	7113	42785	6112	1143	7255
8	794	8206	5443	2057	7500	50285	6286	1026	7312
9	630	8370	5688	2221	7909	58192	6466	930	7396

Table IV Tabulation for Figure 1 (Exponential Trade-in, No Discount).

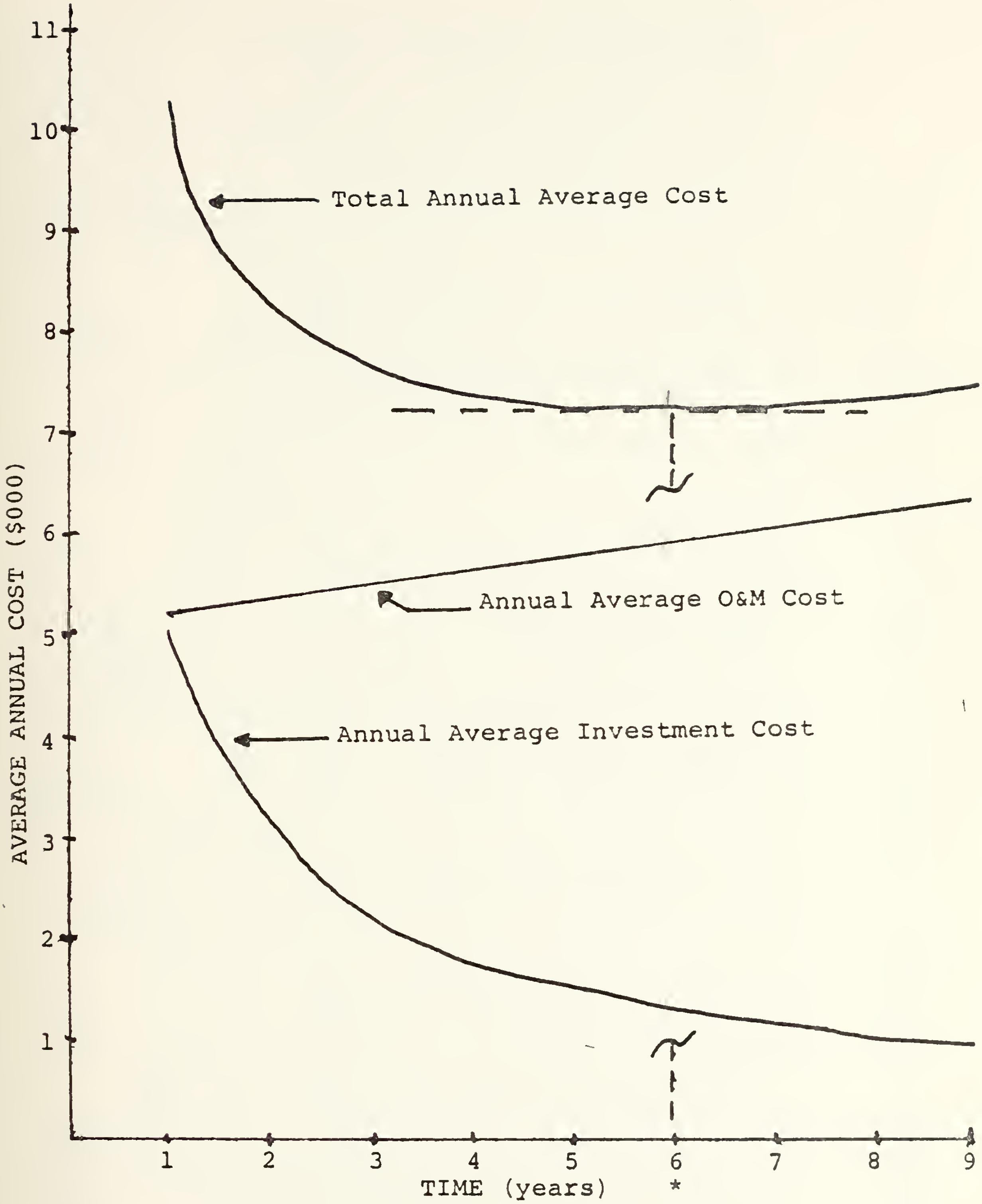


FIGURE 1. General Cost Model. Exponential Salvage Value.

End of Year	Present Value Factor	Capital Recovery Factor	O & M Cost	P. V. of O & M Cost	Σ P.V. O & M Cost	Equivalent Annual O & M Cost	Trade-in	P.V. of Trade-in	P.V. of Investment	Equivalent Annual Investment Cost	Equivalent Total Annual Cost
1	2	3	4	5 = 4 x 2	6 = Σ 5	7 = 3 x 6	8	9 = 8 x 2	10 = Po - 9	11 = 10 x 3	12 = 7 +11
1	.9091	1.1000	5200	4727	4727	5200	3973	3612	5388	5927	11127
2	.8264	.5762	5476	4525	9252	5331	3156	2608	6392	3683	9014
3	.7513	.4021	5768	4334	13586	5463	2508	1884	7116	2861	8324
4	.6830	.3155	6077	4151	17737	5596	1993	1361	7639	2410	8006
5	.6209	.2638	6403	3976	21713	5728	1583	983	8017	2115	7843
6	.5645	.2296	6748	3809	25522	5860	1258	710	8290	1903	7763
7	.5132	.2054	7113	3650	29172	5992	999	513	8487	1743	**7735
8	.4665	.1874	7500	3499	32671	6123	794	370	8630	1617	7740
9	.4241	.1736	8100	3435	36106	6268	630	267	8733	1516	7784

Table V Tabulation for Figure 2 (Exponential Trade-in, Discounted).

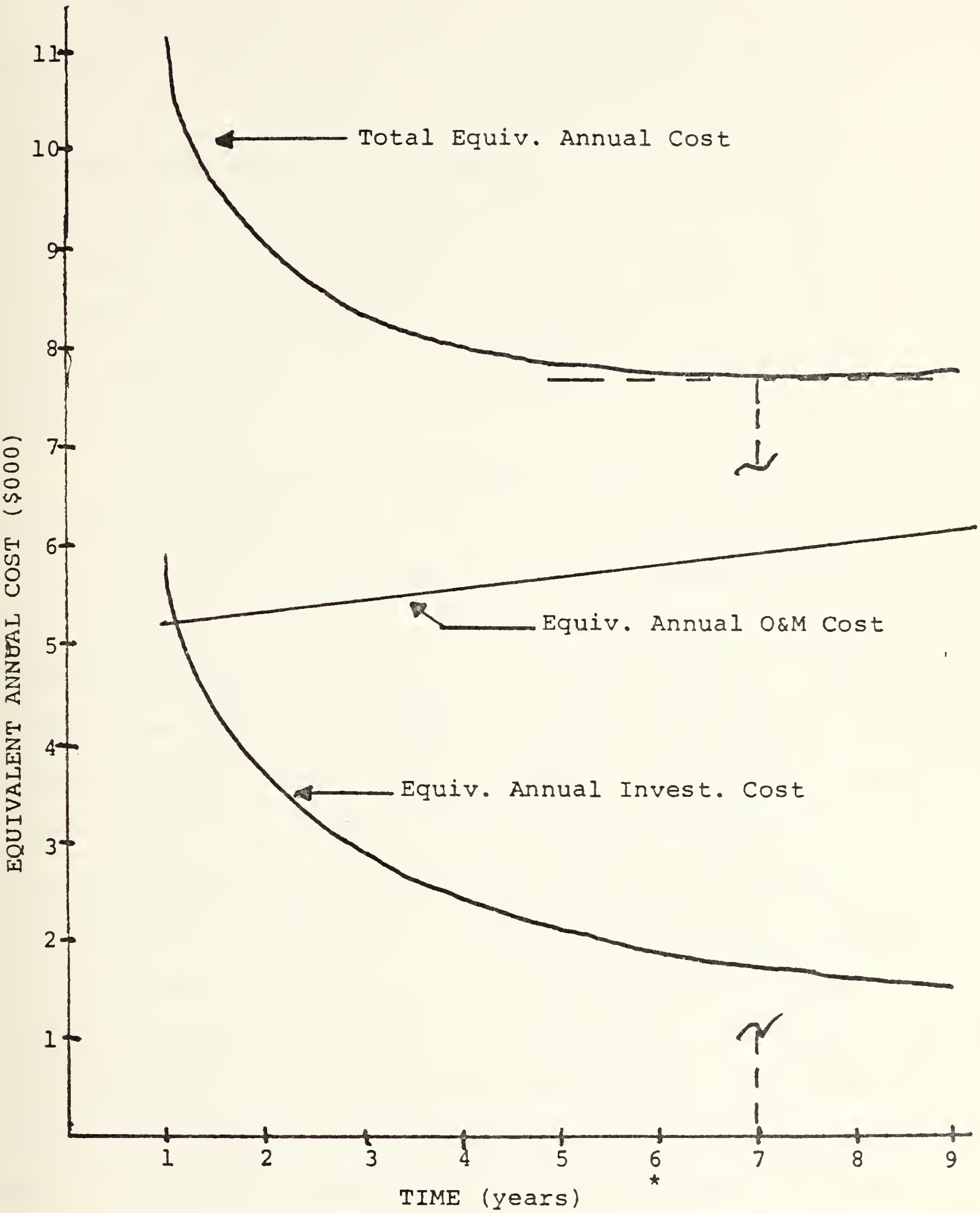


FIGURE 2. General Cost Model, Exponential Salvage Value, Discounted 10%

Discounting all costs to present values results generally in keeping the unit longer than one would if costs were not discounted. As may be seen in Figure 2, the equivalent annual cost reaches a minimum at about 7 years instead of the 6 years shown in Figure 1. Shamblin and Stevens point out that discounting to present values is generally only significant when the discount rate is 20% or greater, or, the initial investment cost is very large (Shamblin).

The costs used to construct Figures 1 and 2 are not entirely unreasonable but were arbitrarily selected. In actual practice, the Navy Supply Systems Command purchases bit and piece repair parts on a volume basis; thus, the maintenance costs may not follow a linear inflation curve. Rather, the inflationary effects may be visible only at such times a large purchase is made – every 4 or 5 years in some cases. Additionally, the salvage value was assumed to decrease exponentially and the exponents were chosen to provide a $500 salvage value at the end of 10 years. Actual salvage values of a TA-75 are available from the Defense Disposal Command but determining the age of any specific unit salvaged is difficult with existing data. The units surveyed are generally deteriorated to the extent that their worth is simply the worth of an equivalent weight of steel scrap. The relevance of these facts will be discussed later.

Although the replacement model presented in Figures 1 and 2 is a simple and effective device for least-annual-cost determination, recent world-wide economic events have precipitated a more intensive examination of existing predictive models. So-called double digit inflation is so rare as to be considered an improbable event in the United States. However, a long-term decline of a high inflation rate or short-term dramatic fluctuations in the inflation rate cause significant problems in replacement models, particularly when the model is not continually revised.

As stated previously, Figures 1 and 2 represent the general replacement (cost) models for a unit such as the TA-75, using both the average and discounted annual costs. In each case the salvage value was assumed to be exponentially decreasing - a characteristic common to automotive-type equipment. Figure 3 and Table VI display the difference caused by assuming no salvage value but discounting at 10%. In Figure 2, the average annual cost over 6 years is $7735 per year. In Figure 3, the lowest total equivalent annual cost occurs at approximately 8 years and approximately $7810 per year. Thus the zero salvage value assigned to the Figure 3 model tends to increase the average annual cost. The 8-year economic life in Figure 3 is a combined result of the 10% discounting and the zero salvage value.

Turning now to a more realistic example, Figures 4 and 5 and Tables VII and VIII display the effects of a constant $500 salvage value with zero and 10% discounting

respectively. The major effect of the constant salvage value is to increase the economic life over that of Figures 1 and 2. This occurs primarily as a consequence of the flatter capital recovery curve resulting from an exponentially-decreasing salvage value presumed in Figures 1 and 2. The differences between Figures 4 and 5 are due solely to the discounting variations previously cited.

To this point, the discussion has centered about the minimum annual cost for the new machine. The existing machine, which will be replaced when economically feasible to do so, continues to accumulate costs annually. The NAVAIR method of computing the time at which the replacement should occur is depicted in Table IX. The Total Equivalent Annual Cost (TEAC) of the new machine is listed for each year of ownership in column 12. Column 13 is the annual average documented cost for the old machine. Obviously, the year in which the comparison is made is of paramount importance. As an example of comparison, consider the following:

a. Characteristics of the new machine are assumed identical with those used to construct Figure 2 and Table V.

b. Assume the old machine has been in service for 5 full years (i.e. new machine year 1 = old machine year 6).

c. Assume maintenance costs for the old machine have been as follows:

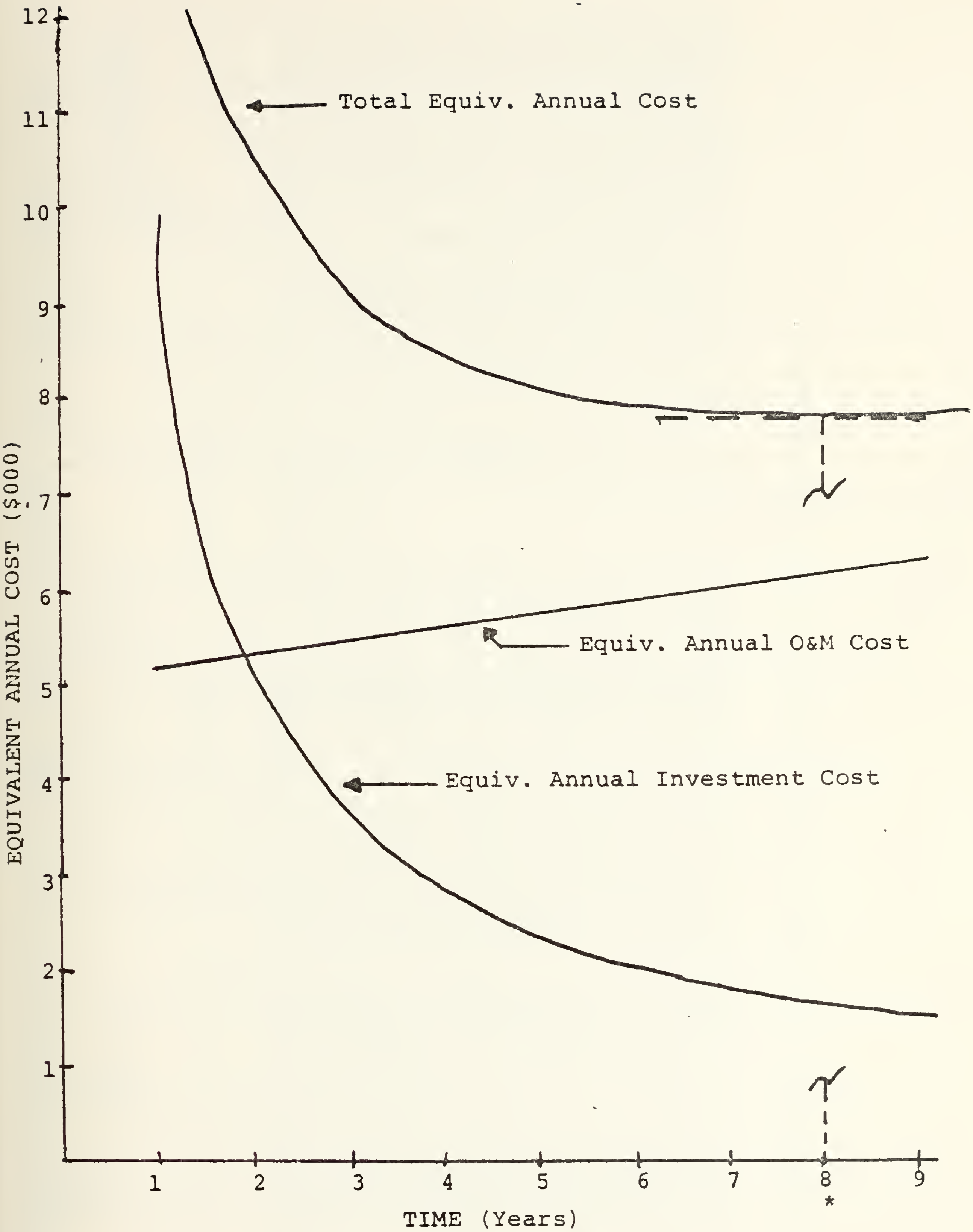


FIGURE 3. General Cost Model, Zero Salvage Value, Discounted 10%

End of Year	Present Value Factor	Capital Recovery Factor	O & M Cost	P.V. of O & M Cost	Σ P.V. O & M Cost	Equivalent Annual O & M Cost	Trade-in	P.V. Trade-in	P.V. of Investment	Equivalent Annual Investment Cost	Equivalent Total Annual Cost
1	2	3	4	5 = 4 x 2	6 = Σ5	7 = 3 x 6	8	9 = 2 x 8	10 = Po - 9	11 = 10 x 3	12 = 7 + 11
1	.9091	1.1000	5200	4727	4727	5200	0	0	9000	9900	15100
2	.8264	.5762	5476	4525	9252	5300	0	0	9000	5186	10517
3	.7513	.4021	5768	4334	13586	5463	0	0	9000	3619	9082
4	.6830	.3155	6077	4151	17737	5596	0	0	9000	2840	8436
5	.6209	.2638	6403	3976	21713	5728	0	0	9000	2374	8102
6	.5645	.2296	6748	3809	25522	5860	0	0	9000	2066	7926
7	.5132	.2054	7113	3650	29172	5992	0	0	9000	1849	7841
8	.4665	.1874	7500	3499	32671	6123	0	0	9000	1687	**7810
9	.4241	.1736	8100	3435	36106	6268	0	0	9000	1562	7830

Table VI Tabulation for Figure 3 (Zero Salvage Value, Discounted).

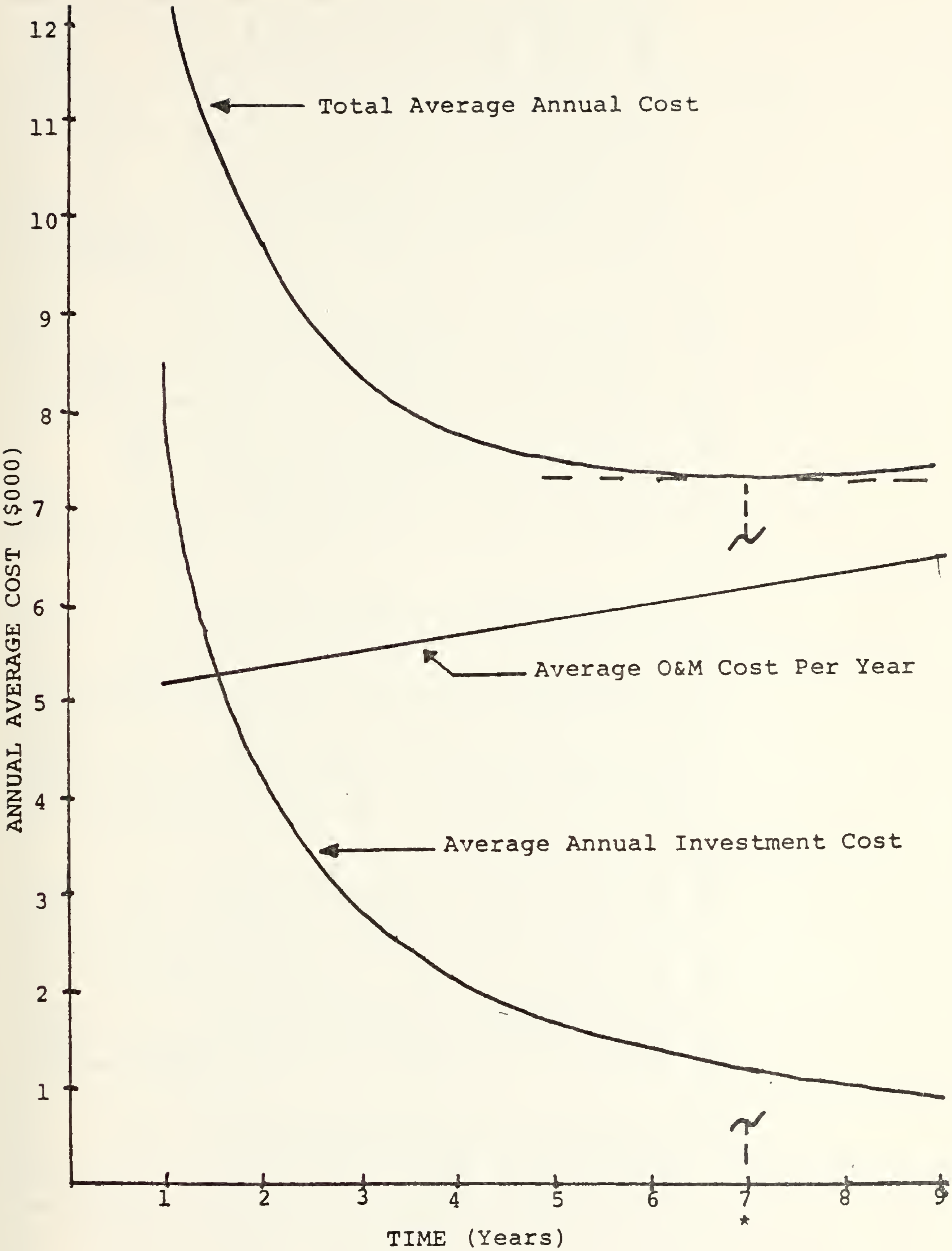


FIGURE 4. General Cost Model, $500 Salvage Value, No Discount

End of Year 1	Trade-in 2	Investment Cost 3 = Po - 2	Operation Cost 4	Maintenance Cost 5	O & M Cost 6 = 4 + 5	Σ O & M Cost 7 = Σ6	Average O & M Cost per Year 8 = 7 / 1	Average Investment Cost per Year 9 = 3 / 1	Total Average Annual Cost 10 = 8 + 9
1	500	8500	4000	1200	5200	5200	5200	8500	13700
2	500	8500	4180	1296	5476	10676	5338	4250	9588
3	500	8500	4368	1400	5768	16444	5481	2833	8314
4	500	8500	4565	1512	6077	22621	5630	2125	7755
5	500	8500	4770	1633	6403	28924	5785	1700	7485
6	500	8500	4985	1764	6749	35672	5945	1417	7362
7	500	8500	5209	1904	7113	42785	6112	1214	**7326**
8	500	8500	5444	2057	7501	50285	6286	1063	7349
9	500	8500	5689	2222	7911	58192	6466	944	7410

Table VII Tabulation for Figure 4 (Constant $ 500.00 Salvage Value).

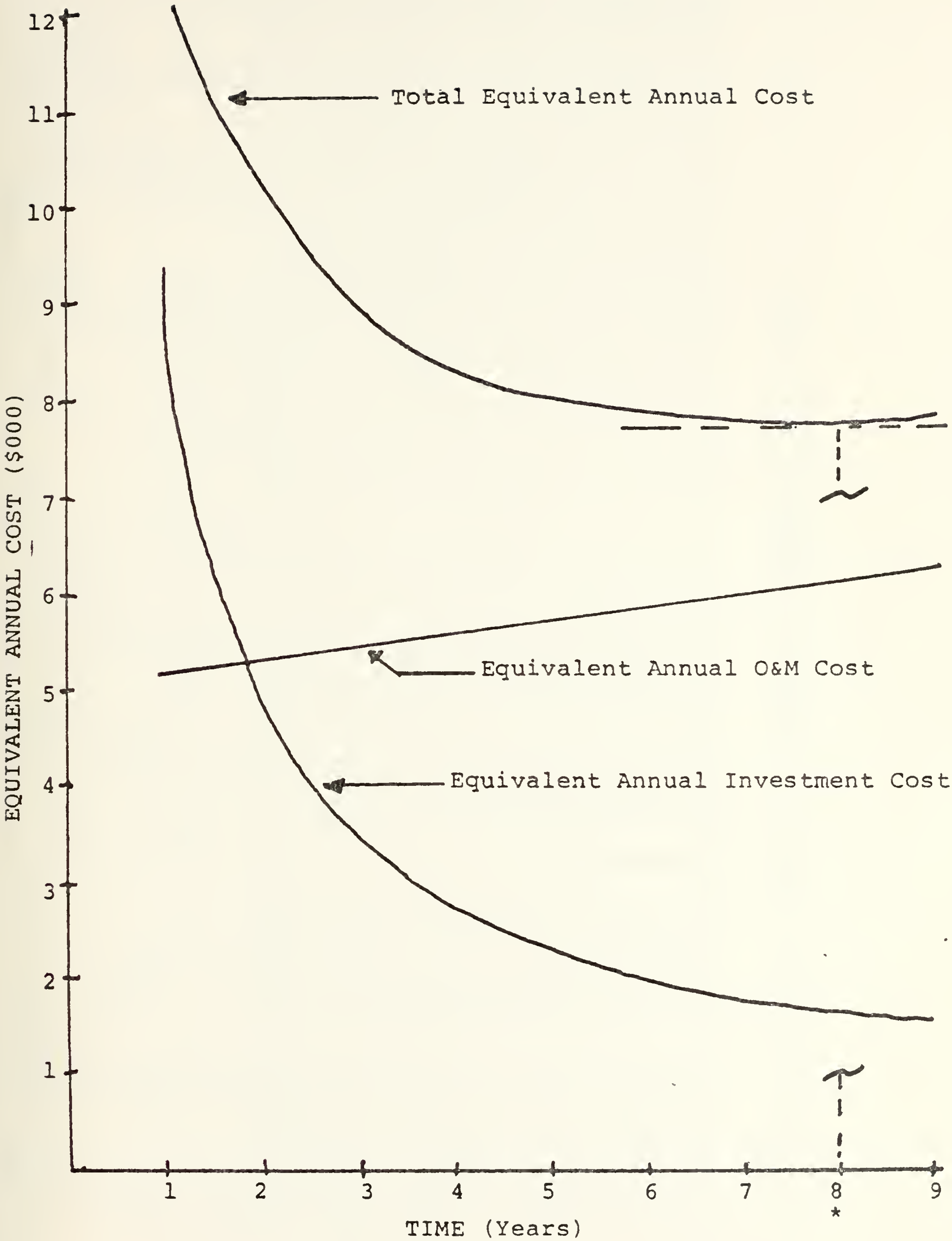


FIGURE 5. General Cost Model, $500 Salvage Value, Discounted 10%

End of Year	P.V. Factor	Capital Recov-ery Factor	O & M Cost	P.V. of O & M Cost	Σ P.V. O & M Cost	Equiv-alent Annual O & M Cost	Trade-in	P.V. Trade-in	P.V. of Invest-ment	Equiv-alent Annual Invest-ment Cost	Equiv-alent Total Annual Cost
1	2	3	4	5 = 4 x 2	6 = $\sum$ 5	7 = 3 x 6	8	9 = 8 x 2	10 = Po - 9	11 = 10 x 3	12 = 11 + 7
1	.9091	1.1000	5200	4727	4727	5200	500	455	8545	9400	14600
2	.8264	.5762	5476	4525	9252	5331	500	413	8587	4948	10279
3	.7513	.4021	5768	4334	13586	5463	500	376	8624	3468	8931
4	.6830	.3155	6077	4151	17737	5596	500	342	8658	2732	8328
5	.6209	.2638	6403	3976	21713	5728	500	310	8690	2292	8020
6	.5645	.2296	6748	3809	25522	5860	500	282	8718	2002	7862
7	.5132	.2054	7113	3650	29172	5992	500	267	8733	1794	7786
8	.4665	.1874	7500	3499	32671	6123	500	233	8767	1643	*7766*
9	.4241	.1736	8100	3435	36106	6268	500	212	8788	1526	7794

Table VIII Tabulation for Figure 5 (Constant $ 500.00 Salvage Value).

Old machine end of year	Documented yearly maintenance cost	Average annual maintenance cost
1	$5000	$5000
2	$6000	$5500
3	$7000	$6000
4	$8000	$6500
5	$9000	$7000

d. Yearly average maintenance cost estimated for year 6 and beyond:

6	$10,000	$7500
7	$11,000	$8000
8	$12,000	$8500

Entering these costs for the defender on the Table IX worksheet, and remembering that "now" is challenger year zero and end of defender year five, the average annual defender maintenance cost for the end of challenger year 3 exceeds the challenger TEAC for the end of year 3 (Defender year 8). Thus, this analysis indicates a replacement must be on-board by the <u>start</u> of challenger year 3, corresponding to the end of defender year 7 to take advantage of the minimum cost.

If this type of analysis is conducted yearly, it is theoretically possible to provide for a replacement far enough in advance to compensate for procurement lead time.

The salvage value of either machine can be an important parameter and can be considered in several ways. At any point in time a machine has had prior salvage values

End of Challenger Year	P.V. Factor	Capital Recovery Factor	Maintenance Cost	P.V. of Maintenance Cost	ΣP.V. of Maintenance Cost	Equivalent Annual Maintenance Cost	Trade-in Value	P.V. of Trade-in	P.V. of Investment	Equivalent Annual Investment Cost	Total Equivalent Annual Cost	Defender Average Annual Maintenance Cost	End of Defender Year
1	2	3	4	5 = 2 x 4	6 = Σ5	7 = 3 x 6	8	9 = 2 x 8	10 = Po -9	11 = 10 x 3	12 = 7+11	13	14
1	.9091	1.100	5200	4727	4727	5200	3973	3612	5388	5927	11127	7500	6
2	.8264	.576	5476	4525	9252	5331	3156	2608	6392	3683	9014	8000	7
3	.7513	.402	5768	4334	13586	5463	2508	1884	7116	2861	8324	8500	* 8 *
4	.6830	.316	6077	4151	17737	5596	1993	1361	7639	2410	8006	9000	9
5	.6209	.264	6403	3976	21713	5728	1583	983	8017	2115	7843	9500	10
6	.5645	.229	6748	3809	25522	5860	1258	710	8290	1903	7763	10000	11
7	.5132	.205	7113	3650	29172	5992	999	513	8487	1743	7735	10500	12
8	.4665	.1874	7500	3499	32671	6123	794	370	8630	1617	7740	11000	13

Table IX Comparison of Challenger Total Equivalent Annual Cost With Defender Average Annual Maintenance Cost.

not realized, thus representing a revenue foregone. Also, the future salvage value of a machine represents a future revenue which has a present value and serves to reduce the capital recovery costs. However, differences in cash flow before taxes will not be influenced by past investments in assets considered for retirement, as a general rule. Past capital expenditures should therefore be considered irrelevant and not as revenues foregone since military capital investments are not taxed and do not suffer depreciation (Grant and Ireson).

In making decisions on whether or not to continue an asset in service, the capital costs of extending its service should be based on its present net salvage value at the end of the anticipated service extension. An alternative method is to assume zero capital costs for the defender and subtract the present net defender salvage value from the challenger's contract price before computing challenger capital costs. In this method, the capital recovery costs are based on the amount of new monies required rather than on the total investment (Grant and Ireson). This is the method used in the annual cost method previously described and illustrated by Figure 2 and Table V.

III. THE CURRENT CGSE RETIREMENT PROGRAM

The Naval Air Systems Command CGSE Retirement Program outlined in NAVAIRINST 4411.1 (Commander, 1971) contains specific responsibilities for primary action and supporting commands. NAVAIR (AIR-417), is assigned the overall responsibility for the CGSE retirement program. They are responsible for the determination of policy and the coordination between the Type Commanders, Aviation Supply Office, and the Naval Air Systems Command Representative's efforts. AIR-417 submits a list of equipments to be retired in the succeeding fiscal year. An additional list is required of equipment that is forecast to be retired in the budget year and for the budget year plus one. Requirements for replacement equipment are computed and submitted to the CGSE Acquisition Manager, NAVAIR-534.

NAVAIR (AIR-534) allocates the CGSE procurement funds to provide a balanced inventory. AIR-534 also provides distribution instructions for the procuring activity based upon retirement data furnished by AIR-417.

Naval Air Engineering Center (NAEC) develops criteria based upon cost-analysis techniques which are the basis upon which retirement decisions are made. NAEC also reviews the 3-M data and depot-level data pertinent to the retirement program and functions as the technical advisor to the NAVAIR retirement program coordinator assigned by AIR-417. Retirement

lists are submitted annually to the Program Coordinator identifying the type equipment code, serial number, and the current custodian of CGSE units that have exceeded their economic life as determined from MDCS data for each unit and the theoretical annual cost model calculations for each type unit.

Naval Air System Command Representatives (NASCREPS) provide the depot level data and commercial rework data needed for the CGSE retirement program. In conjunction with the Type Commanders, NASCREPS authorize local survey or shipment to a depot level activity for cannibalization.

Type Commanders allocate new and in-use assets to preclude shortages created by the retirement of specific serial-numbered units.

Aviation Supply Office (ASO) provides the distribution for replacement CGSE units. ASO prepares budgets and initiates procurement actions for replacement items of CGSE nominated for retirement under its management cognizance.

The CGSE retirement program is based upon data derived from the MDCS. The retirement decision criteria developed by NAVAIRENGCEN are based upon the Annual Cost Method previously described.

IV. CGSE RETIREMENT PROGRAM PROBLEMS

Any policy employing a model such as the ones described herein is effective only to the extent logisticians adhere to that policy. Unfortunately, for a variety of reasons, the current CGSE Retirement program has been only partially effective.

This system or any other system must have as its cornerstone a sound base upon which the system decisions are made. The Maintenance Data Collection System (MDCS) for CGSE is manipulated for local purposes as well as being susceptible to erroneous higher level interpretation. In addition it is highly susceptible to human data-entry errors.

In recent reports, the JG-75 had a 38% reporting error in valid meter hours and the TA-75 had a 24% reporting error in valid hour meters. (NAEC 1973, NAEC 1975) Only those units with reported valid meter readings are used for input to the model. With a 24% to 38% error in only one specific reported item, the accuracy of remaining data entries must be questioned.

The MDCS was designed as a data collection system to manage aircraft maintenance. MDCS easily accommodates the three-levels-of-maintenance concept but is not entirely compatible with CGSE maintenance policy which more nearly resembles a two-level concept (Organizational/Intermediate-Level and Depot-Level). As a consequence of this

incompatibility, source data is often entered incorrectly simply due to a lack of applicable provisions for this unique situation. The collated data available to upper management is in turn subject to misinterpretation.

Another serious deficiency in the current CGSE retirement program is the lack of coordination between the retirement decision-making process and the procurement process. Since the existing model is exercised for each individual serial-numbered unit, a replacement should theoretically be provided for each retirement decision. Basic procurement economics, however, dictate that some economic order quantity (EOQ) be established to minimize contract and set-up costs and also to take advantage of any learning curve benefits. The EOQ consideration dictates that some units must be retained beyond the point at which the minimum total average annual cost is attained. This situation is not untenable, provided the replacement action does not consume an unreasonable amount of time.

Beyond a certain undefined economic life extension, however, the model developmental and operational cost rapidly transcends expected benefits. Additionally, enthusiastic participation in assuring source data accuracy will be mitigated if timely equipment replacements are not experienced.

Another major problem that is associated with this cost model or any other model that may be developed for common ground support equipment is that the dollar expenditures

documented for CGSE often do not reflect the actual amount expended or the circumstances that precipitated the expenditures.

As examples consider: (1) the case of several units that are in a repair state causing the remaining operating units to fulfill all the requirements. This would cause the operating costs of these few operating units to be higher than average and (2) the dollars actually spent per unit come from many different "pots of money" and there does not currently exist a means of determining what funds were actually spent on a particular end item of CGSE. The dollars actually expended to repair an item of CGSE will be different based upon where and by whom the unit was repaired. If the Aircraft Intermediate Maintenance Department (AIMD) initiates and completes the repair totally within and by means of its own facilities, the documented costs will generally be accurate. These costs will be the sum of the labor cost, consumable materials used and/or the cost of replacement components.

Given the present retirement program methodology and model parameters, a repair which involves removal and replacement of a component at the I-Level (AIMD) and component repair at the D-Level (Naval Air Rework Facility — NARF) will also result in generally accurate model inputs.

AIMDs, however, have other means available to restore a unit to operating condition. A component may be cannibalized from another inoperative unit, for example. If

the proper code is not entered on the Maintenance Action Form, NAEC can only interpret the action as dollars spent on a new component from stock. The net effect is a double cost for one purchased component. Further, the AIMD may send a defective component to a commercial firm for repair. The removal and replacement time would likely be documented correctly. The component overhaul cost would not be documented in the MDCS. This cost will either be lost to the system or be assigned an incorrect value at NAEC.

Navy activities have several funds available to effect repairs. Although funds are allocated for specific purposes, an energetic logistician will generally use any fund available to increase operational readiness. There being no established procedure to document these expenditures (even if the individual wanted to disclose his ingenuity), the expenditures are lost as model inputs.

Components salvaged from surveyed units likewise are not entered into the system at their true cost. This lack of uniform cost accountability for specific CGSE units causes the cost replacement model to yield inaccurate results.

Additive to the problem of incorrect dollar repair bills being reported for each unit is the problem of data timeliness. As with any information system, the cost to obtain rapid and accurate information increases as the speed and accuracy requirements likewise increase. The problem that

arises using MDCS data is that cost data is not required to be submitted until the repair action is complete. Numerous items are cannibalized from one unit to repair many other CGSE units. The component cost will show upon the robbed unit when in fact the cost is caused by other units. The cannibalized unit may also remain in this robbed-of-parts condition indefinitely since there is no requirement to report units which have been inoperative for an excessive period of time. Meanwhile, the unit can continue to incur costs that do not get reported into the system. In addition, literally years may go by before the CGSE unit that has exceeded its economic life is, if ever, replaced. To illustrate, a unit whose uniform annual cost is approaching the threshold for retirement, goes hard down for a major component. Since the specific component is not in stock, several similar units are repaired with parts cannibalized from the inoperative unit in order to meet "operational" requirements. Eventually all the parts are received, the inoperative unit is placed back into operation and the data enters the system months after being initially generated. The information for this particular serial-numbered unit finally reaches NAEC which determines that the cost now makes this unit a candidate for retirement. The unit must now be reported as a unit that needs replacement. However, by instruction, the list of units to be replaced is an annual list which could have been just published. Therefore it will be another year before this unit will be

placed on the list of units requiring a replacement. If there are not enough like units to trigger the procurement (i.e. the EOQ threshold is attained) the unit will continue to be used for a longer, indeterminate time.

Equipment maintenance policies have a direct bearing on equipment retirement and replacement actions and the total cost of owning a particular piece of equipment. Currently, the Navy specifies a preventative maintenance (PM) policy that requires periodic maintenance and inspections even if there is no apparent need. Although the need for routine inspection is accepted (check the oil level, tire pressure, water levels), the forced repair or replacement of parts based only on hours or usage frequency should be evaluated frequently. In a recent work (Brosh), the optimal policy was determined to be replacement/repair of components only upon failure. This result was obtained when a comparison of the following five maintenance policies were investigated for a fleet of vehicles: (1) replace components upon failure, (2) planned replacement of components irrespective of age at predetermined intervals, with no information available as to life distribution, (3) replacement as in the second case, but based upon valid information. When the unit is called in for repairs, the component is replaced. (4) Unplanned replacement of subsets of components irrespective of age whenever a failure occurs and (5) unplanned replacement of a subset of components based upon an age limitation. Another similar view (ARORA) is stated as:

> ... one can rationalize many maintenance practices followed in real life. We can conceive of a situation where it may be meaningful to provide maximal (or minimal) maintenance in the beginning, in the middle, toward the end or throughout the life of the system. For example, in the case of automobiles, it may be advisable to provide maximal maintenance during the middle period.

Repair model utility is conditional upon the same factors cited for the replacement models. The ultimate reasons for PM are twofold: (1) cost is minimized and/or (2) operational readiness (or availability) is maximized. If cost is the prime consideration, the annual PM costs should exceed the Corrective Maintenance (CM) costs. Should the reverse be true, many factors could be responsible, but certainly the PM policy and the repair model itself should be examined carefully. In a recent study the Naval Air Engineering Center (NAEC) studied 410 TA-75A/Bs and reported 24,641 total days Not Operationally Ready (NOR) for maintenance (NAEC 1975). Of these, 3,995 days were for PM and 20,646 days were for CM: a CM-to-PM ratio of 5.17 to one. The obvious conclusion is that the Navy maintenance policy considers availability the prime consideration with cost as a secondary consideration. Telephone conversations with NAEC engineers, however, confirm that in those cases where the Navy has a large equipment inventory and a surplus over minimum operational requirements, the policy is to consider cost as the paramount consideration.

Valid alternate items in the CGSE inventory complicate use of the existing replacement model. The problem posed by

these alternate items is that by their existence, procurement action to replace retired CGSE is delayed since a unit capable of performing most of the same functions is on hand. Conversely a unit which has exceeded its model-determined economic life may by the current directive be replaced even though a perfectly acceptable alternate may be available.

The current model assumes that the cost projections for the new unit will be similar to the documented costs of the older unit. Unless allowances are made for inflationary effects, technological improvements and anticipated reliability differences, the computed economic life of the replacement unit will have little relation to reality. As a consequence of this comparison with faulty assumptions, budgetary estimates may be significantly over or under-stated.

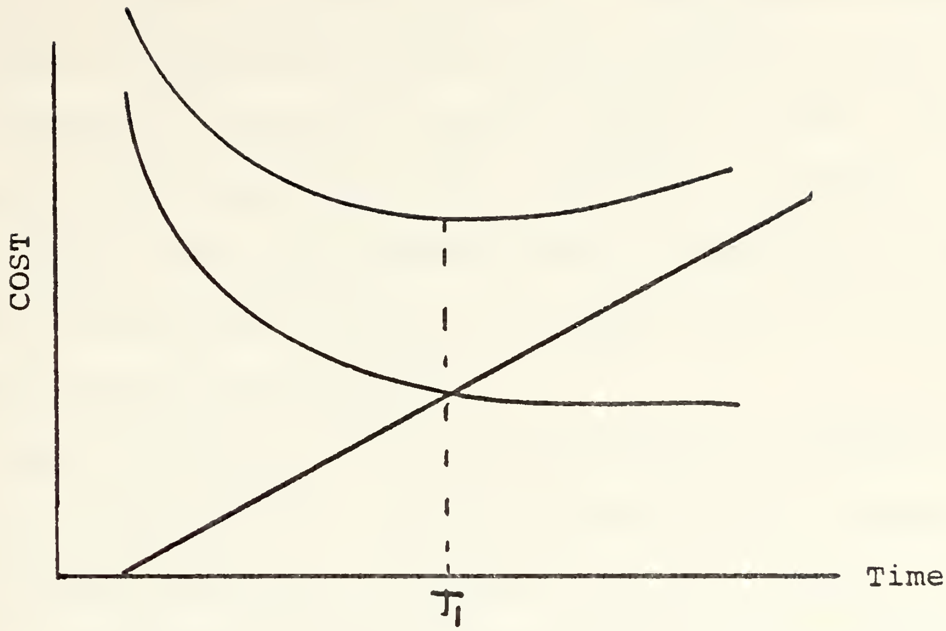
Unless the replacement unit is an exact duplicate of the retired unit, the logistician faces a problem in predicting future operating and maintenance costs for use in the model. Since the basic reason for using a model is to compare the cost of operating an old unit longer with the future cost of a replacement item, any errors in predicting costs for the new machine will result in an erroneous management decision. The net result, of course, is that the old equipment may be replaced too soon or too late. In either event, the decision would not be optimal and avoidable costs would be incurred.

Another cost factor having a major impact on future cost data for the system is the cost of making a unit like new — i.e. a complete overhaul or "renewal". The current model

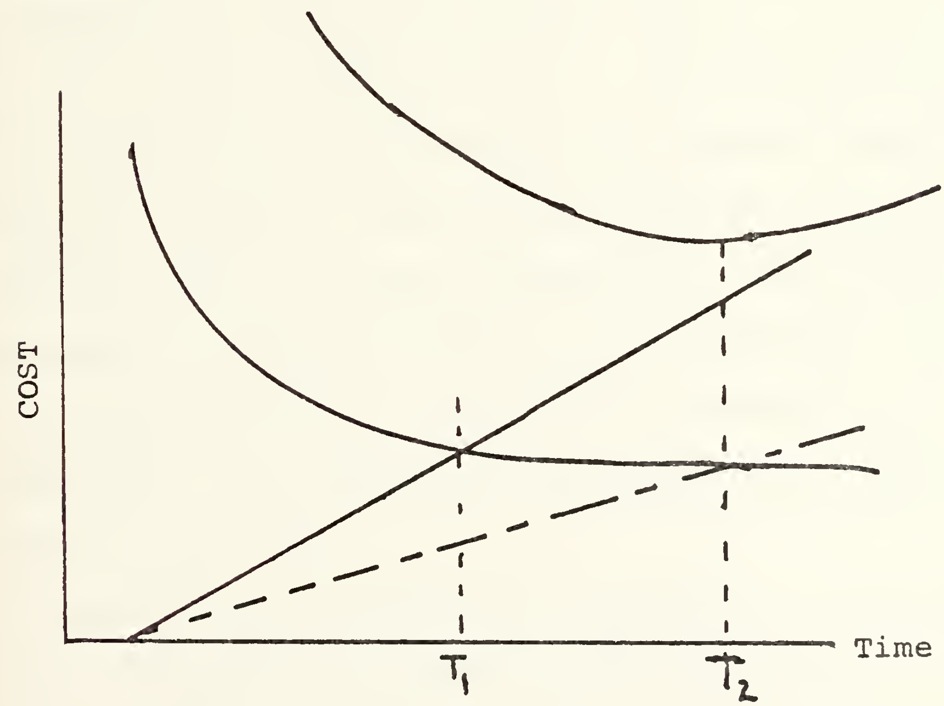
does address a situation involving the trade-offs between a complete overhaul and a new procurement. To illustrate the effect of a make-like-new policy on an existing equipment model, consider Figure 6 which depicts a unit at the end of its economic life T_1 and the expenditure of sufficient funds to restore the unit completely. The effect, depending on the cost of the overhaul, causes the average yearly cost to decrease, thus increasing its life past T_1 to T_2. The total effect may be slight or significant depending upon the amount of expense incurred to overhaul the unit, the age of the unit at the time of overhaul, the original unit price and the effect renewal has upon subsequent annual O&M costs. In any event, the renewal policy should be examined as a viable alternative to replacement.

Compounding the renewal policy problem, there appears to be no limit as to the number of make-like-new repairs that a unit could undergo before it becomes uneconomical to perform the renewal action. The maintenance activity which determines the unit is a good candidate for a successful renewal effort does not have ready access to the accumulated maintenance costs which serve as the primary model input. In the TA-75 example, the Operational Logistic Support Plan (OLSP) specified only one overhaul for each unit, although the criteria for that specification are not disclosed (NAVAL AIR, 1974).

This rigid guidance does not provide for an investigation into the possible economic advantage of an operating-life



a. Immediate identification and replacement at T_1 (end of original economic life).



b. Renewal action at T_1 and resultant new (longer) economic life.

FIGURE 6. Effect of complete renewal on annual cost of ownership and length of economic life.

extension through a renewal action. The projected cost of a renewal is generally available only after the unit is transported to a Naval Air Rework Facility (NARF) and an Inspection and Evaluation (I&E) completed. Further, the post-renewal annual maintenance cost is difficult to predict but may be generally estimated to approximate new-unit costs if these costs are available.

AIMDs and Depot activities use different methods to document repair costs: the depot method being exogenous to the MDCS and requiring a separate collection and evaluation effort. An effort to include MDCS reporting as a NARF requirement has been in process for several years, but progress is slow.

CGSE may be overhauled legally by the AIMD custodian, thus circumventing the one-overhaul rule as a result of a unique provision in NAVAIR 4790.2A: this provision designates certain large AIMDs as possessing the expertise and manpower sufficiency to perform depot-level overhaul of engine, transmission and drive-train components. The special authorization (termed SX function) was intended to implement the stated NAVAIR policy to perform maintenance at the lowest feasible level. The costs are documented on a MAF and serve as input to the model.

The model must be continually updated so as to reflect the true acquisition price of the challenger when the investigation to replace the old unit is made. This acquisition price must also be representative of the true procurement

cycle, i.e. an educated assumption of economic factors such as inflation must be applied to the estimated price at the time the replacement will actually be made.

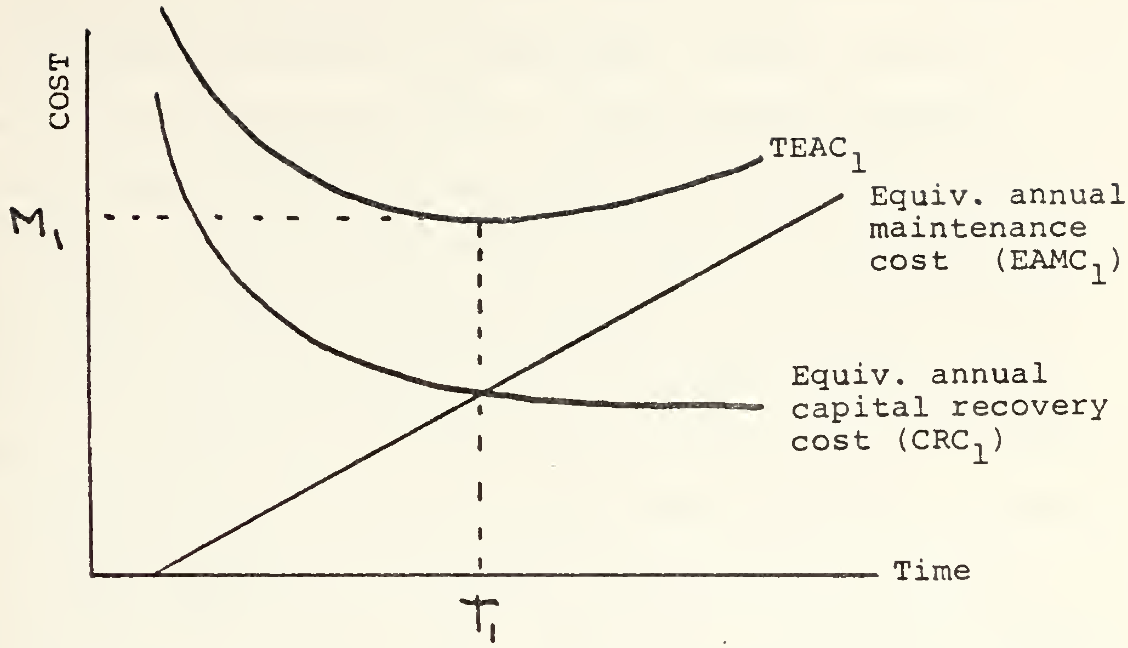
Procurement lead time and inflationary uncertainties dictate the replacement would actually occur before the most economic time in the unit's life-cycle.

If it were possible to identify the need for replacement and immediately provide that replacement, the situation depicted in Figure 7 would prevail. The total annual equivalent cost experienced over the economic life of the defender would be the optimum which could be realized.

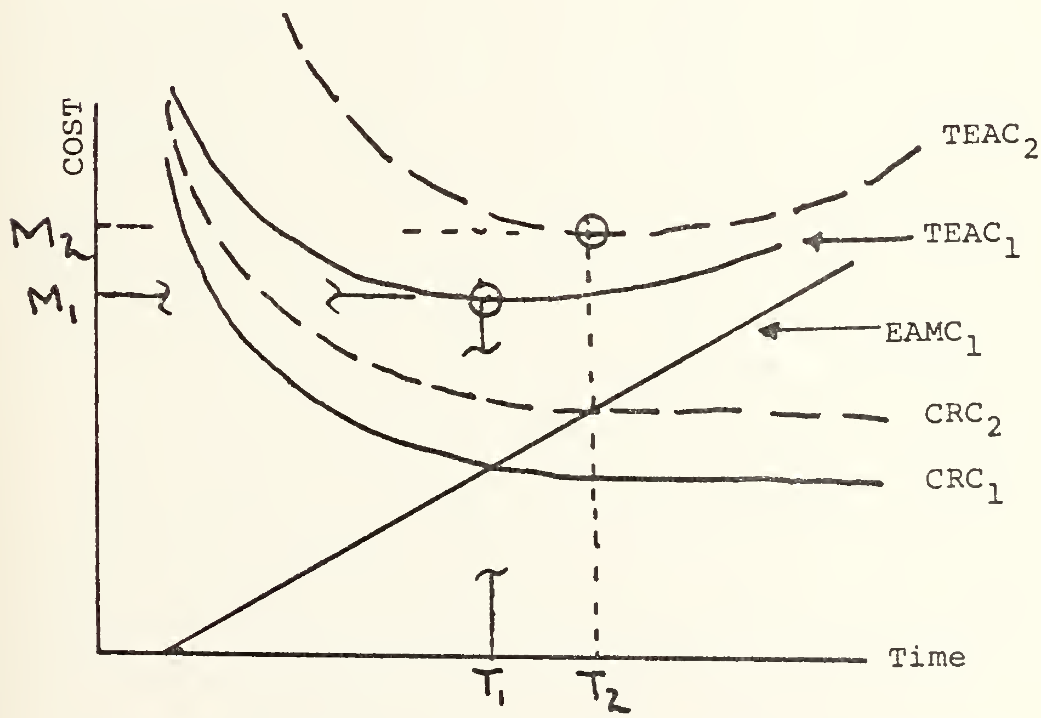
Considering the normal procurement lead time, however, if the realization of need for replacement occurs at T_1 and the actual replacement occurs at T_2, the TEAC experienced over the defender's lifetime (M_2) is clearly not optimal.

It is therefore apparent that some means must be available to trigger an investigation into possible replacement action well <u>before</u> time T_1. Otherwise, it would be necessary to conduct an analysis of each serial-numbered unit every year after (say) the fourth year or so to ensure time T_1 is still lead-time into the future.

Additionally, to insure model output viability, the state-of-the-art with respect to reliability and maintainability must be monitored or estimated yearly. These factors can have a significant impact upon the costs utilized in the comparison between challenger and defender.



a. Immediate replacement at end of economic life T_1



b. Identification of end economic life (T_1) and replacement at time T_2 (procurement lead-time away)

FIGURE 7. Changes in TEAC caused by procurement delays. Subscripts 1 and 2 refer to original and revised costs respectively

Initially, the current NAVAIR model is used for only five equipment categories. These are: mobile electric power plants, air conditioners, liquid oxygen equipment, hydraulic test stands and tow tractors. These five types of equipments are in turn broken up into 79 type-equipment codes representing 79 different models. The total actual onhand inventory was, and is now, precisely unknown. The NAVAIR retirement program directive requires that all CGSE be eventually placed under the retirement program. In view of the cost involved to exercise the model for existing equipments and in view of the reservations presented herein, further expansion into other CGSE categories should be questioned intensely.

V. CONCLUSIONS

There are pressing reasons from both an economic and operational standpoint to replace aging CGSE with new equipment. Determining the lowest annual cost of ownership for existing equipment is extremely attractive particularly in view of the public pressures to minimize defense expenditures.

Although it is mathematically attractive to predict the minimum cost life (economic life) and operational life (physical life) of an asset, it is more of an ideal than a working reality.

The decision to replace CGSE is almost always made just before the actual replacement or when the actual need for a replacement unit if known as a result of factors that are analyzed at the immediate time. This is done for a number of reasons: first, the future cost data of a replacement and in particular the maintenance cost are uncertain factors when the asset is first obtained. Secondly, the evaluation of the existing unit is dependent upon an imperfect data collection system. Thirdly, recent experience with widely-fluctuating inflation rates almost mandates a yearly assessment of the replacement status. Nonetheless, determination of a minimum cost interval is possible under certain conditions.

Assuming future asset costs can be predicted with a reasonable degree of accuracy and assuming that the

replacement CGSE will have characteristics identical to the original unit, then consideration of only the maintenance cost will yield these results: (1) with a constant annual maintenance cost or sporadic maintenance costs, there will be no minimum annual average or equivalent annual cost and thus, no specified economic life. (2) Only if the documented annual maintenance cost rises each year will a minimum occur to indicate minimum cost of ownership. When there exists a predictable and rising trend in maintenance cost, it is possible to formulate a model that may be used to find the minimum cost replacement interval. It is this model that the Naval Air Engineering Center uses for the CGSE retirement program.

The current model, however, employs various assumptions which may mitigate its value. The assumption that all serial-numbered CGSE exhibit a rising annual maintenance cost must be questioned. The effects of inflation are recognized in the rate of interest chosen for the model, but the maintenance and operating costs are not adjusted for inflation prior to exercizing the model. The operational costs are assumed identical for both the challenger and the defender, thus eliminating them as differential costs for the comparison. The combination of the inflation rate and the time frame in which the comparison is made may render this assumption invalid.

The maintenance policy established for the unit is extremely important to the computed economic life of either the challenger or the defender. The engineered service life of the asset is seen to have minimal importance in the economic replacement decision. The number and frequency of overhauls, whether minimum component overhauls or a "make-like-new" renewal action, can extend the service life of an asset and might be utilized as a least-cost alternative to obviate replacement actions.

Existence of older alternatives to the prime CGSE unit complicates the process of inventory validation and obscures the obvious need for new procurement. Given the historical concern for minimizing the budget, the obvious tendency is to delay procurement until the operational need becomes critical.

Without a strong, consistent link between retirement decisions and procurement initiation, replacement modeling can never assume a role of importance.

Fleet perceptions of untimely replacement actions and inconsistent retirement decisions will serve to perpetuate incorrect source data submissions and prevent strong fleet program support essential to the modeling viability.

While the NAVAIR program costs are not known, the economic advantage of a modeling effort for such a wide range of equipment types and models as compared to the routine subjective evaluation of a fleet maintenance officer

must be proved before the retirement model can be assumed viable. While fleet personnel are not always aware of impending obsolescence ten years hence, they are generally capable of determining whether a unit is capable of restoration or should be replaced (although they are generally unaware of the long-term average annual cost implications).

Finally, the maintenance policies established for aircraft tow tractors in particular, and CGSE in general, do not appear to be sufficiently comprehensive and do not appear to reflect the current national economic conditions. Nor do they recognize the possibility that the unit may well suffice functionally for generations of new aircraft in the foreseeable future. Furthermore, the exhibited ratio of PM/CM appears to be out of balance leading to the conclusion that maintenance policies must be revised to minimize annual maintenance costs.

VI. RECOMMENDATIONS

The NAVAIR Retirement Program should be discontinued and reviewed in its entirety. The model used is considered adequate for certain CGSE units with the caveat that the underlying assumptions must be carefully reviewed for applicability. A procurement price threshold should be established, below which the model will not be used. Exercizing a model for CGSE originally costing less than the system cost to generate the information is not considered cost effective. Items of CGSE whose maintenance costs are also less than the information systems generation cost should be deleted to maintain a cost effective system.

Examination of other methods to indicate replacement requirements should be undertaken. Considering the plethora of low-cost CGSE, inclusion of these items in a formal mathematical model would appear to have little utility. This reservation would apply particularly to those equipments which are simple tools, or non-motorized, portable units. Replacement requirements for these equipments could be initiated at the custodian level and passed via the logistic chain of command to the NAVAIRSYSCOM.

The custodian could use methods such as the maintenance cost per utilization hour, as documented in the MDCS, to signal the requirement for a replacement request. When an

Economic Order Quantity of replacement requests is accumulated, NAVAIR could initiate procurement action.

Consideration should be given towards maintaining a minimum ready stock of CGSE, and establishment of an inventory model to minimize procurement delays associated with the replacement decision (described on pages 43, 53, and 54.

While the procurement program appears to be fully capable of efficient, effective action, innovative procurement techniques should be investigated to minimize delays and costs. A continuous production contract with small firms might possibly serve the purpose of replenishing attritions and satisfying the inventory model. Further, since large firms pay an economic penalty for such small production, this action would be a naturally suitable vehicle for government to assist small business.

The TYCOMs and major fleet users (particularly Naval Air Stations) should be included in policy formulation discussions. Unique operating problems would then be considered and reconciled before implementation. As an example, GSE MDCS reporting anomalies must be corrected before any replacement model will enjoy validity. Prompt replacements for equipment to be surveyed will automatically serve to decrease reporting errors, but further emphasis must be placed in this important area.

Finally, an investigation should be conducted into the advisability of incorporating CGSE procurement, retirement and replacement into a system which makes the user accountable

for the economics of equipment utilization as well as being accountable for the operational readiness. Current budgetary responsibilities lie with the Systems Commands who are assisted by inputs from the TYCOMs. The fleet, in essence, has custody of a free good in the sense that their only obligation is to operate within a specific allocation of funds. By providing the fleet (possibly) or the TYCOM (certainly) the information necessary to optimize economic utilization of existing assets, these activities will be induced to minimize capital and operational costs and will realize a commensurate increase in availability and operational readiness.

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